PROPERTIES OF SEVERAL TYPES OF SALTED YOLK
AND FUNCTIONALITY IN MAYONNAISE

by

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INTRODUCTION

Food emulsions are a significant part of the food industry. Milk, a natural oil-in-water emulsion, has long been an important and nutritious part of the human diet (Graf and Bauer, 1976). As food scientists discovered and studied other natural emulsions, man-made food emulsions began to appear. Cake batters (Shepard and Yoell, 1976), ice cream (Berger, 1976), margarine (Brown, 1949, Weiss, 1970), and meat products such as sausage and frankfurters (Schut, 1976) are just a few examples. Another man-made food emulsion, whose production and consumption has grown rapidly, is mayonnaise.

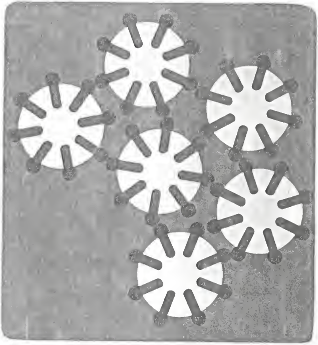
The legends connected with the invention of mayonnaise have been described by Robinson (1924). Although there is a divergence of opinion as to its origin, mayonnaise has been known for many centuries (Robinson, 1924). From 1917 to 1927, economic and industrial changes brought about shifts in American dietary habits and mayonnaise became a diet staple involving a large scale industry (Epstein, 1937). Finberg (1955) estimated that approximately 39 million gallons of mayonnaise and salad dressing were produced in 1938. By 1953 that figure had risen to over 100 million gallons. In 1983, approximately 175,686,000 gallons of mayonnaise and 62,469,000 gallons of salad dressing were produced, for a total production of over 238 million gallons (Preston, 1983). This rise in consumption and production seems to be due to a continuing increase in sandwich and salad consumption (Finberg, 1955).

Standards of Identity for mayonnaise define the product as a semi-solid emulsion made of egg yolk, edible vegetable oil, and acetic or citric acid. It also may contain salt, spices or spice oils, natural sweeteners, and various natural flavoring ingredients. Oil content must be not less than 65% by weight and the product must contain at least 2.5% acetic acid by weight. Citric acid in the form of lemon or lime juice may replace the acetic acid at a minimum level of 2.5%. The egg yolk may be from separated yolk or whole egg, and may be in the liquid, frozen, and/or dried forms. This ingredient provides emulsifying properties and gives the mayonnaise a pale yellow color, which may not be intensified by any other ingredient.

EMULSIONS

Many incomplete definitions of emulsions have been compiled by Becher (1957), who also gave his own, more technical definition. Simply stated, an emulsion is "a two-phase system of immiscible liquids" (Lynch and Griffin, 1974) that "posses(es) a minimal stability" (Becher, 1957). One phase is in the form of finely divided droplets whose diameters generally are larger than 0.1μ (Becher, 1957). This dispersed, internal, or discontinuous phase is suspended in the continuous or external phase. Emulsion stability is increased by the addition of an emulsifier, which lowers the interfacial tension. The lipophilic (oil loving) portion of an emulsifier orients itself with the oil phase of an emulsion, while the hydrophilic (water loving) portion orients with the water phase, forming a shell around the droplets of the dispersed phase (Figure 1). By orienting itself at the interface, the emulsifier prevents the dispersed particles from coalescing and separating out, thereby increasing the emulsion's stability (Lynch and Griffin, 1974). The technical aspects and mechanisms of emulsions can be found in the abundant literature (Clayton, 1928, Clayton and Morse, 1939, King, 1941, Becher, 1957).

FIGURE 1. Orientation of an emulsifier around the droplets in an emulsion.



Emulsion properties

Emulsion properties may be physical or chemical in nature, or both. Although it is difficult to characterize all facets of emulsions, their properties generally depend on the properties of the continuous phase and the proportion of the continuous phase to the dispersed phase (Lynch and Griffin, 1974). According to Lynch and Griffin (1974) and Bennett (1947) the eight major properties of an emulsion are:

Appearance. The ingredients used, their color and the difference in refractive index, and the particle size of the dispersed phase all influence the appearance of an emulsion. A particle size of 0.5 to 5μ yields an opaque emulsion. Emulsion color usually depends on the color of the continuous phase.

Dispersability and Emulsion Type. Oil-in-water emulsions can be dispersed in and diluted by water, while water-in-oil emulsions can be dispersed in and diluted by oils.

Viscosity. Emulsion viscosity depends largely on the viscosity of the external phase and the ratio of external to internal phases. In low internal-phase-ratio emulsions, such as milk, viscosity is similar to that of the external phase. As the concentration of the internal phase increases, viscosity also increases. When the volume of the internal phase becomes greater than that of the external phase, a high internal-phase-ratio emulsion, such as mayonnaise, is formed. Theoretically, only 74% of an emulsion's total volume can be occupied by the dispersed phase when the droplets are spherical. However, high internal-phase-ratio emulsions have more than 74% of the emulsion in the dispersed phase, causing distortion of the dispersed droplets. This distortion results in a higher degree of plasticity, as well as allowing particle size and charge to have a greater effect on emulsion viscosity.

Particle size. The diameter of the internal phase globules usually is taken as the particle size. Fine emulsions contain particles with small diameters, while coarse emulsions contain large globules. Good stability generally is associated with fine, uniform particle size. The type and quantity of emulsifier, the order of addition of ingredients, and the amount of work done to form the emulsion all influence particle size.

Particle charge. A charge is present on the dispersed particles of almost all emulsions. This charge is extremely important in maintaining stability of small particle size emulsions, but is less important in high viscosity emulsions, such as mayonnaise.

Conductivity. Oil-in-water emulsions are strong electrical conductors, while water-in-oil emulsions are poor conductors. This property provides one means of identifying emulsion types.

pH. The effects of pH on emulsion stability only recently have begun to receive research attention. Changes in emulsions often can be achieved by pH adjustments.

Stability. The stability of an emulsion refers to how long the internal phase will stay dispersed under normal conditions of shipping and storage. When the droplets of the dispersed phase coalesce and the phases separate, the emulsion is referred to as "broken". The rate at which coalescence occurs depends on the type and concentration of the emulsifier, the size of the dispersed droplets, the charge on the particles, the emulsion viscosity, and the transportation and storage conditions to which the emulsion is subjected.

Hydrophile-lipophile balance

The hydrophile-lipophile balance (HLB) is probably the most common means of choosing an emulsifier. HLB is "an expression of the relative simultaneous attraction of an emulsifier...for the two phases of the emulsion system being considered" (Lynch and Griffin, 1974). The chemical composition and the extent of ionization of an emulsifier apparently determine it's HLB value. These values range from 1 to 20.

In general, emulsifiers with HLB numbers below 9 are lipophilic and tend to form water-in-oil emulsions; those with HLB numbers of 11 to 20 are hydrophilic and tend to form oil-in-water emulsions. Those with HLB values of 9 to 11 are classified as intermediate (Lynch and Griffin, 1974). The type of oil to be used also is influenced by the HLB value. Emulsifiers with HLB numbers of 7 to 12 are necessary to form oil-in-water emulsions with corn or soybean oils, while one with an HLB number of about 5 is required to form an oil-in-water emulsion with cottonseed oil (Powrie and Tung, 1976).

A combination of two or more emulsifiers with different HLB values often is necessary to form a stable emulsion (Powrie and Tung, 1976). Stability at a given HLB value varies with the emulsifiers used. The HLB values of emulsifier combinations can be found by multiplying the weight proportion of each emulsifier by it's HLB value and then adding the resulting numbers.

Emulsion types

Emulsion systems can be divided into two categories (Lynch and Griffin, 1974):

1. Those consisting of droplets of oil dispersed throughout an aqueous medium are usually referred to as oil-in-water (o/w) emulsions.

2. Those in which droplets of water are dispersed throughout an oil or fat medium are termed water-in-oil (w/o) emulsions.

Most food emulsions, including mayonnaise, are of the o/w type (Lynch and Griffin, 1974). Mayonnaise, though, differs from other o/w emulsions since large quantities of oil are emulsified in a relatively small amount of water. Mayonnaise, therefore, tends to be more unstable than many other food emulsions, but many of the problems associated with its manufacture can be applied to other products (Corran, 1943).

Mayonnaise formulation varies considerably with the processor, as can be seen by comparing the commercial formulas given in Table 1 (Corran, 1943) and Table 2 (Weiss, 1970). There are a number of factors that influence the characteristics of mayonnaise. Corran (1943) listed these factors as:

1. egg yolk
2. the relative volume of the phases
3. the emulsifying effect of the mustard
4. the method of mixing
5. the hardness of the water
6. viscosity

TABLE 1. Mayonnaise Composition
(Corran, 1943)

INGREDIENT	%
Oil	75.0
Salt	1.5
Egg yolk	8.0
Mustard	1.0
Water	3.5
Vinegar (6% acetic acid)	11.0

TABLE 2. Mayonnaise Composition
(Weiss, 1970)

INGREDIENT	WEIGHT %
Salad oil	77.0-82.0
Fluid egg yolk[1]	5.3-5.8
Vinegar (100 gr.)	2.8-4.5
Salt	1.2-1.8
Sugar	1.0-2.5
Mustard flour[2]	0.2-0.8
Oleoresin paprika[3]	
Garlic, onion, spices[2]	
Water to make 100%	

[1] Egg solids, 43%. May substitute whole or fortified egg, fluid or dry, on a total solids basis.

[2] Spice oils, oleoresins may be substituted.

[3] Optional where characteristic color is desired.

EGG YOLK AND EMULSIFICATION

Egg yolk, itself a natural o/w emulsion (Baldwin, 1977), also is known to be an efficient emulsifying agent for other o/w emulsions (Corran, 1943). Intended by nature to produce a chick (Stadelman, 1977), the yolk is a complex mixture. Although it may vary, yolk generally contains 15.7-16.6% protein, 31.8-35.5% lipid, 0.2-1.0% carbohydrate, and 1.1% ash (Powrie, 1977).

Egg yolk fractions

Egg yolk contains about 28.3% phospholipid (largely lecithin) and 5.2% cholesterol (Powrie, 1977) for a lecithin/cholesterol ratio of about 5.4:1. Research by Corran and Lewis (1924) showed that lecithin favored an o/w emulsion while cholesterol favored the w/o type. Antagonistic effects were seen when both substances were present. Inversion of an emulsion occurred when the lecithin/cholesterol ratio was 8:1 when both compounds were in the aqueous phase, and at the 1:1 to 2:1 ratio when the cholesterol was present in the oil phase.

Sell et al. (1935), using the above results as a base, added both cholesterol and lecithin to mayonnaise preparations. The cholesterol had no effect on mayonnaise preparation or stability when added in small amounts, although the emulsion weakened when four times as much cholesterol as is normally present in yolk was added. Lecithin, on the other hand, lowered consistency and decreased stability of the mayonnaise in every case tested. After further studies, those researchers concluded that the emulsification ability of egg yolk is not due to any one compound, but to an unstable complex of lecithin and protein which they termed "lecitho-protein".

Detrimental effects of lecithin on egg yolk emulsification capacity also have been described by Yeadon et al. (1958), by Varadarajulu and Cunningham (1972a), and by Cunningham (1975), who also found that 2 to 4% lecithin significantly increased egg yolk viscosity, but decreased yolk foaming capacity and significantly decreased sponge cake volume.

Chapin (1951) found that the water soluble/ether insoluble portion of egg yolk, designated as the livetin portion, possessed poor emulsifying properties. However, when it was combined with the water insoluble portion, designated as the lipoprotein portion, emulsification ability was increased. The lipoprotein alone had a slightly higher emulsification capacity than the combination product. Phospholipids added to livetin reduced emulsification capacity.

The emulsification ability of yolk was attributed to the lipoprotein and livetin fractions by Vincent et al. (1966), who suggested that those fractions aided in emulsion formation by reducing surface tension.

Davey et al. (1969) studied the emulsifying properties of three crude egg yolk protein fractions: lipovitellin, livetin, and lipovitellenin. All reduced initial emulsion drainage. Lipovitellenin alone increased subsequent drainage, but reduced subsequent drainage when combined with either lipovitellin or livetin. Combinations of lipovitellin and livetin increased subsequent drainage. Optimum emulsion stability occurred when all three protein fractions were present. Although freezing the fractions resulted in an emulsion less stable than those made from fresh yolk or fresh combined fractions, freezing and thawing did not significantly decrease the emulsifying ability of any of the fractions or combinations of fractions.

Varadarajulu and Cunningham (1972b) also studied the emulsifying properties of the lipovitellin, lipovitellenin, and livetin fractions of yolk. Results showed that none of the fractions, alone or in combinations, were as good emulsifiers as fresh yolk.

Liquid egg yolk

Several studies determined the effect of the hen's dietary fats on the emulsification capacity of egg yolk. Jordan et al. (1962) found that the type of fat in the hens' diets produced no significant effect on emulsion separation. Pankey and Stadelman (1969) also found no significant differences in emulsification capacity of egg yolk from hens fed rations supplemented with corn, soybean, olive, safflower, or hydrogenated coconut oils.

Davey et al. (1969) found that native yolk gave more stable emulsions after 60, 90, and 120 minute drainage periods than emulsions made from recombined lipovitellin, livetin, and/or lipovitellenin. Fresh yolk and fresh recombined fractions yielded more stable emulsions than frozen yolk or frozen fractions.

Varadarajulu and Cunningham (1972a) found that emulsification capacity of liquid yolk decreased as dilution with albumen increased, and suggested that this was due to the lower solids content or to interactions between albumen proteins and yolk fractions. They recommended that commercial yolk manufacturers could improve their products by keeping albumen content below 20%.

Pasteurization did not significantly affect emulsification capacity of commercial fresh yolk containing 48 to 49% solids (Varadarajulu and Cunningham, 1972b). Homogenization after pasteurization improved emulsion stability. Albumen-free yolk heated to 61°C showed no significant changes in emulsion stability, but emulsification capacity was significantly increased by heating the yolk to 63°C.

These same researchers (Varadarajulu and Cunningham, 1972c) studied the influence of breed, strain, and age of bird on emulsification capacity. Eggs from Brown Leghorns had twice the emulsification capacity of eggs from White Leghorns. Emulsification ability of eggs decreased as birds aged. Low social dominant strains of both the Rhode Island Red and White Leghorn breeds produced eggs with greater emulsification ability than eggs from the high social dominant strains.

Emulsifying properties of pasteurized and stored salted (10% NaCl) liquid yolk were studied by Cotterill et al. (1976). In the high temperature-short time method, samples were held for 5 minutes at temperatures from 62°C to 78°C, while in the low temperature-long time method, samples were held at 52°C for 2 to 8 days. Since there were no emulsification differences between yolks treated by the two methods, the authors concluded that salted yolk could be pasteurized at high temperatures without damage to emulsifying properties.

Frozen egg yolk

Frozen yolk containing 10% NaCl is the most common form used in mayonnaise preparation (Weiss, 1970). The added salt inhibits microbial growth during thawing (Weiss, 1970), and reduces the gelation that occurs in frozen plain yolk (Powrie et al., 1963, Meyer and Woodburn, 1965). If frozen yolk is allowed to thaw evenly, the resulting smooth, heavy paste will be about the right consistency for high quality mayonnaise (Kilgore, 1935).

Studies on the use of frozen-thawed yolk in mayonnaise have produced variable results. Kilgore (1935) reported that a higher percentage of frozen yolk than of fresh yolk was required to produce a mayonnaise of a given viscosity. Miller and Winter (1951), on the other hand, found that frozen yolk produced a much stiffer mayonnaise than did fresh yolk. Dilution of the thawed yolk was necessary before acceptable mayonnaise could be produced. Johnson (1970) also found that frozen yolks produced a stiffer mayonnaise than fresh yolks, and sugared frozen yolk produced a stiffer mayonnaise than salted frozen yolk. Yolks containing both salt and sugar produced the least stable mayonnaise.

Davey et al. (1969) found that emulsions prepared with fresh yolk were more stable than those prepared with frozen yolk. Johnson (1970), on the other hand, found that frozen yolk gave more stable emulsions; however, yolk containing 5% NaCl gave the most stable emulsions. Several studies, which dealt with the influence of freezing on emulsion stability, were conducted at about that same time. Jaax and Travnicek (1968) found that emulsion separation increased as freezing rate increased when unpasteurized yolk containing no additive was used. Method of freezing - either with liquid nitrogen or in a household freezer - had no significant effect on stability of emulsions made with salted yolks. Palmer et al. (1969a, b) studied the influences of pasteurization, freezing, and acidification on emulsification capacity of egg yolk. Freezing and storage at either 0°F or -10°F for up to four months caused no loss of emulsification ability in either pasteurized or unpasteurized salted yolks. Freezing at -20°F for 5 to 6 days followed by storage at 0°F resulted in no loss of emulsifying properties, but freezing at -20°F and storage at -10°F for 1 to 4 months was detrimental to both pasteurized and unpasteurized yolks. Acidification in combination with pasteurization, followed by freezing and storage also damaged the emulsification ability of salted yolk.

Yolk solids

Although yolk solids are used by the mayonnaise industry, few studies have been conducted on their functionality in mayonnaise. Several investigators, though, have studied the influence of dehydration on yolk emulsifying properties.

Chapin (1951) reported that spray-drying increased yolk emulsification capacity; however, vacuum drying decreased emulsifying power.

Carlin (1955) showed that rehydration of dried yolk with acetic acid instead of water apparently decreased its emulsification capacity. Data on dried yolks produced from 1949 to 1952 indicated that mayonnaise comparable to controls could be produced using 50 grain acetic acid, but solids from 1953 produced a similar mayonnaise when either 50 or 100 grain vinegar was used. The author concluded that either 50 or 100 grain vinegar could be used to produce mayonnaise from yolk solids available at that time.

Lyophilized yolk was the subject of a study by Rolfes et al. (1955). The use of fresh, frozen, and spray-dried samples for comparison indicated that lyophilization harmed yolk emulsifying properties. This detrimental effect was less when the yolk was diluted before freeze-drying.

Schultz et al. (1966) reported that drying of yolk resulted in a rapid increase in extractability of the "free lipids" which were extremely detrimental to the emulsifying capacity of yolk.

Zabik (1969) studied the emulsification ability of freeze-dried yolks, as well as of foam-spray-dried yolks and spray-dried yolks. Frozen yolks were used for comparison. Averages of emulsion separation at three pH levels indicated that frozen yolks produced the most stable emulsions, followed by freeze-dried and foam-spray-dried. Spray-dried yolk produced the least stable emulsions.

Varadarajulu and Cunningham (1972b) also showed that spray-drying was detrimental to yolk emulsification ability. Initial separation was significantly greater for spray-dried yolk, although emulsion separation at 120 minutes was similar for all the samples tested. The authors also reported apparent superior emulsification ability with samples processed in a Buflovak drier than with yolk dried in a Rogers drier, but the differences were not significant.

Determination of emulsification capacity and stability

Very few tests have been devised to determine emulsification capacity of egg yolk directly. Pankey and Stadelman (1969) added corn oil dropwise to a mixture of 0.5 g of whole yolk and 15 ml of distilled water in a microblender cup of a Waring blender until emulsion disruption occurred. Emulsification capacity was taken as the amount of oil that could be incorporated before disruption occurred. Cotterill et al. (1976) used two types of phase inversion techniques to determine emulsification capacity. In the "monophasic" titration, 10 g of yolk and 81 g of corn oil were mixed together in the metal bowl of a Kitchen-Aid mixer to form a w/o emulsion. The emulsion then was back-titrated with water to the inversion point, which was determined by change in electrical resistance. In the "bi-phasic" titration, electrodes on opposite sides of a beaker containing 20 g of yolk were used to measure resistance. The o/w emulsion was titrated with oil until resistance went rapidly from 0 to 5×10^6 ohms, which was considered the inversion point. An additional 10 ml of oil then was added to convert the emulsion to w/o. This emulsion then was back-titrated with water to the inversion point, which was at 0 ohms. The amounts of water or oil required to reach the inversion points were used as a determination of emulsification capacity in all tests. A method similar to that of Pankey and Stadelman (1969) was reported recently by Young et al. (1983). In this procedure, 15 g of yolk, 20 ml of 0.8M acetic acid, 20 ml of corn oil, and 0.5 g of NaCl were mixed in an Osterizer blender at maximum speed. Corn oil was added dropwise from a cylinder until the emulsion broke, as determined by a sudden drop in viscosity. The total oil (the original 20 ml plus the amount added from the cylinder) divided by the weight of yolk used was taken as the emulsification capacity.

Stability of emulsions seems to be a more common way to test indirectly yolk emulsification efficiency. Numerous methods have been developed to determine stability of both simple emulsions and of mayonnaise.

Jordan et al. (1962) and Davey et al. (1969) used a method that involved blending 15 g of yolk, 15 g of corn oil, and 85 g of deionized water in a stainless steel blender cup at 28 to 29°C. After blending 1 minute at 50 volts and 5 minutes at 110 volts, 15 g portions were transferred to graduated 15 ml centrifuge tubes and placed in a test tube rack. Emulsion separation was recorded after 30, 60, 90, and 120 minutes and was interpreted as an indication of stability.

Variations on the above procedure have been used by several researchers. Zabik (1969) adjusted the water content of the formula to allow for moisture previously added to the frozen-thawed yolks, increased the speed of initial homogenization to 55 volts, and decreased the amount of emulsion placed in the centrifuge tubes to 10 mls. Varadarajulu and Cunningham (1972a) modified the procedure to use a Virtis homogenizer rather than a blender. Emulsion separation was recorded only after 60 and 120 minutes.

A procedure similar to that of Varadarajulu and Cunningham (1972a) had previously been developed by Jaax and Travnicek (1968). Emulsions consisting of 8.5 g of yolk, 11.0 g of corn oil, and 46 ml of deionized water were prepared by blending for 90 seconds in a Virtis homogenizer set at medium speed. The formed emulsions were then transferred to 100 ml graduated cylinders, and separation was recorded every 30 minutes. Total separation was recorded at the end of 3 hours. Johnson (1970) also used this basic procedure, but replaced the corn oil with soybean oil and recorded separation for 4 hours.

Kilgore (1933b) tested mayonnaise stability by shaking a sample of the emulsion with an equal weight of water, pouring the solution into a graduated cylinder, and allowing it to stand for 24 hours. The amount of creaming was used as the measure of stability.

Stability of mayonnaise often has been determined by simply storing samples at room temperature until visible separation occurred. Kilgore (1933a) stored samples at room temperature for 1 year before determining the amount of separation. Chapin (1951) stored emulsions in a one-half pint Mason jar at approximately 21°C. The length of time required for the first appearance of water was taken as the stability measurement. Johnson (1970) evaluated the stability of mayonnaise by observing the presence or absence of oil separation when samples were stored at room temperature for 2, 4, and 6 weeks.

Centrifuging until phase separation occurred was suggested by Bennett (1947) as a test of emulsion stability. Miller and Winter (1951) centrifuged 10 g samples for 15 minutes and then used the amount of liquid separation as a measure of stability. Rolfes et al. (1955) employed an International centrifuge at 2000 rpm for 15 minutes to test mayonnaise stability. The percent oil separation, determined on a weight basis, was taken as the measure of stability. Varadarajulu and Cunningham (1972a) also used an International centrifuge, but revised the test conditions to 5000 rpm for 30 minutes.

RELATIVE VOLUME OF THE PHASES

Mark (1921) studied the emulsification of oil in liquid egg yolk by taking samples every 10 seconds during emulsion formation and monitoring oil dispersion microscopically. Four conclusions were drawn from the data:

1. If the proportion of egg to oil was kept below a certain maximum, a stable emulsion could always be formed regardless of temperature or method of beating.

2. If the amount of oil exceeded a certain minimum, the continuous phase became the oil and no permanent emulsion could be formed.

3. If the proportion of egg to oil was kept between the minimum and maximum, formation of a stable emulsion became dependent on variables such as temperature and mixing procedure.

4. If vinegar was used to dilute the egg, the amount of oil that could be emulsified permanently increased greatly during initial addition of oil. As emulsion viscosity increased, the maximum amount of oil that could be emulsified approached the amount emulsified when undiluted egg was used.

The amount of oil that could be emulsified in a given amount of egg yolk was reported by Robinson (1924) to depend on the type of oil being used. Amounts of oil that could be emulsified in 15 g of yolk ranged from 296 g for pure Italian olive oil to 432 g for Wesson oil. The amount of water present also was cited as an influence on the amount of oil that could be emulsified.

Gray and Southwick (1929) found that the consistency of mayonnaise decreased rapidly as moisture content increased.

Due to the presence of "free" water, Kilgore (1935) considered fresh yolk to be too light in body to produce a good initial emulsion. The author reported that some means of holding this excess moisture must be utilized with fresh yolk to start the smooth, fine-grained emulsion necessary for high quality mayonnaise.

Corran (1943) reported that the usual procedure in mayonnaise production was to emulsify the total amount of oil in a small amount of the aqueous phase before addition of the remainder of the aqueous phase. Although the large concentration of oil tended to give rise to a w/o emulsion, the emulsifying agents prevented this, and the large amount of oil was cited as a major factor in mayonnaise formation. He also reported that addition of oil to all of the aqueous phase resulted in an emulsion of very low viscosity.

Lowe (1955) found that 40 g of oil could be emulsified initially in approximately 15 g of egg yolk when seasonings and vinegar were added to the yolk. These data indicated that mayonnaise formed most readily with a small quantity of oil.

EMULSIFYING EFFECT OF MUSTARD

In ·1932 Kilgore studied the emulsifying effect of mustard on mayonnaise. Three tests were used to evaluate mustard: 1) foaming power of a mustard/water solution, 2) stability of oil drops on the surface of a mustard/water solution, and 3) stability of simple o/w emulsions using a solution of mustard and water as the water phase and sole emulsifying agent. Results showed that emulsion stability increased as the mustard level increased up to 4%. When oil was dropped onto the surface of a 4% solution of mustard, the drops stayed completely apart, indicating stabilization due to the mustard. In the third experiment, a 4% solution of mustard formed and maintained a fairly heavy emulsion. The author concluded that mustard exerts a stabilizing effect on emulsions.

In 1933(a), Kilgore studied the effect of mustard on the permanence and consistency of mayonnaise. Mustard was found to have considerable influence on the stability of mayonnaise. Consistency of the emulsion was found to be influenced greatly by not only the chemical and physical properties of mustard, but by the method of incorporating mustard into the mayonnaise.

After determining the effects of mustard on mayonnaise characteristics, Kilgore (1934) reported three methods for testing mustard to be used in mayonnaise: moisture holding power, development of flavor, and keeping quality. Characteristics of several types of mustard also were described.

Corran (1943) studied the effect of mustard on oil/lime water mixtures that resulted in w/o emulsions when shaken. Data indicated that 2.1% fine mustard flour or 2.5% coarse mustard flour caused inversion of the emulsion to o/w. Further tests conducted with a mobilometer confirmed that mustard confers a measure of stability to mayonnaise.

METHOD OF MIXING

Robinson (1924) reported that more oil could be emulsified when intermittent mixing was used than when the beating was continuous. Speed of oil addition also was cited as a factor influencing mayonnaise production.

Hall and Dawson (1940) tested two methods of emulsion formation. In the American method, the emulsifying agent and acid were combined, followed by the gradual addition of oil. In the compromise method, a small amount of oil was first added to the emulsifying agent, followed by the addition of acid, and then the addition of the remainder of the oil. Each method was tested under two conditions - oil was added either from a height of 6 inches above the emulsion or was added beneath the emulsion surface. Results showed that the introduction of oil beneath the emulsion surface improved stability, consistency, and homogeneity of the formed emulsion. The authors also found the compromise method to produce emulsions superior to those produced by the American method. The best emulsions were produced when the compromise method with addition of oil beneath the emulsion surface was used.

Corran (1943) found that the stability and form of emulsions was influenced by a number of method-of-mixing factors. Those factors included the amount and composition of the aqueous phase added during the first stage of mixing, the time of beating, and the degree of agitation. Results of tests conducted by that author indicated that, of the various conditions tested, a beating time of 5 minutes without initial addition of vinegar produced the most viscous mayonnaise.

Lowe (1955) reported that the kind of bowl used to make mayonnaise influenced the emulsion. Placing small quantities of yolk in a large mixer bowl was cited as one cause of failure in making mayonnaise. The duration of beating and resting periods had a measurable influence on the emulsion. The addition of vinegar at various stages in the making of mayonnaise affected the consistency of the mayonnaise.

WATER HARDNESS

Water hardness was cited by Corran (1943) as a minor factor in mayonnaise production. Calcium salts, as well as salts of other divalent metals, tend to form w/o emulsions, thereby decreasing mayonnaise stability (Corran, 1943, Lowe, 1955).

VISCOSITY

Viscosity is an important property of egg yolk to be used for mayonnaise manufacture. Numerous studies have been conducted on egg yolk viscosity. Chapin (1951) suggested that the "emulsifying index", which was based on final emulsion viscosity, was influenced partially by initial emulsifier viscosity. Kilgore (1935) stated that frozen-defrosted yolk of good quality would be a smooth heavy paste which was about the right consistency for mayonnaise.

According to Payawal et al. (1946), native yolk containing 49 to 49.5% water has a viscosity of approximately 800 centipoises (c.p.s.). Pasteurization temperatures above 62.5°C caused a considerable increase in egg yolk viscosity.

Pearce and Lavers (1949) showed that freezing resulted in an irreversible increase in egg yolk viscosity. Reduced viscosity was noted in defrosted yolk when vigorous mechanical treatment was applied prior to freezing. As freezing time increased from 0.2 to 39 hours, a progressive increase in viscosity occurred. Viscosity of yolk also was found to increase as defrosting time increased from 0.03 to 24 hours.

The effects of freezing on yolk gelation, which can be considered a large increase in viscosity, was studied by Lopez et al. (1954). Colloidal milling of the egg yolk prior to freezing inhibited gelation under certain conditions. Salt (NaCl) added to yolk before milling, freezing, and frozen storage produced yolk with a higher degree of gelation than that with no NaCl, while emulsion stabilizers and destabilizers did not inhibit gelation either with or without colloidal milling. None of the substances tested, including trisodium citrate, trisodium ethylenediaminetetracetate, NaCl, sugars, and glycerol, produced a normally flavored yolk and inhibited gelation. Sugar, NaCl, and glycerol partially prevented yolk gelation, but resulted in marked flavor changes. Quick freezing by immersion in either a dry-acetone-ice mixture or in liquid nitrogen partially inhibited gelation.

Decreased yolk gelation was associated with increased freezing rate, and quick freezing combined with rapid defrosting further reduced yolk gelation.

The effect of salt (NaCl) on yolk viscosity was studied by Jordan and Whitlock (1955). Untreated yolk was considerably more viscous than either egg white or whole egg magma. As salt levels were increased from 1 to 5%, those differences in consistency were found to become increasingly greater. Results indicated that the viscosity ratio between the yolk containing 5% salt and the untreated yolk was greater than 4 to 1.

Marion and Stadelman (1958) also found that the addition of salt increased the viscosity of fresh, unfrozen yolk. Gelation was reduced significantly by increases in both freezing and defrosting rates. Several additives, including hexane, NaCl, and sucrose, were found to effectively reduce frozen yolk gelation.

Powrie et al. (1963) found that viscosity change in frozen-thawed yolk was dependent on the time-temperature relationship of frozen storage. Salt, sugar, and cysteine all decreased gelation of frozen yolk. Urea caused a definite increase in native yolk viscosity, with a urea level of 0.416 moles/100 g yolk causing the yolk to gel within 85 minutes.

Increasing age of eggs resulted in decreased yolk viscosity in studies by Meyer and Woodburn (1965). Cysteine- and water-treated unfrozen yolk had similar viscosities, while NaCl-treated yolks were more viscous than the control. Sucrose caused the most reduction in viscosity. Water was slightly less effective than cysteine in inhibiting gelation in frozen-defrosted yolk, while NaCl was the most effective in inhibiting gelation in stored frozen-defrosted yolk.

Jaax and Travnicek (1968) found that both NaCl and sugar reduced gelation of frozen-defrosted yolk. Yolk frozen in a freezer was more viscous than yolk frozen in liquid nitrogen, and liquid nitrogen was less effective in retarding gelation in treated yolk than in yolk containing no additive.

Palmer et al. (1969a, b) found that pasteurization did not change the effect of frozen storage on salted yolks, but caused a slightly increased viscosity in unfrozen salted yolk. Viscosity of frozen-defrosted yolks stored below -10°F increased as shear rate decreased, while unfrozen salted yolk viscosity was independent of shear rate. Acidification caused a considerable increase in viscosity with pasteurization and frozen storage each accentuating that increase.

Studies conducted by Davey et al. (1969) indicated that the increased viscosity of frozen-defrosted yolk could be due to increased viscosity of the lipovitellenin fraction as a result of freezing. However, results for this constituent were highly variable.

Scalzo et al. (1970) studied viscosities of 5 commercial egg products. They showed that all products, including yolk, produced a linear relationship between shear stress and shear rate at temperatures ranging from 5 to 60°C. Viscosity of the egg products, therefore, was concluded to be independent of shear rate.

Shear rate also was a factor studied by Chang et al. (1970). Viscosity of native yolk with 52.5% solids decreased as shear rate increased. Decreases in viscosity of pasteurized yolk with increased shear rate also were noted. Thin albumen added at levels up to 20% decreased viscosity of native yolk, and increases in yolk viscosity due to heat damage were reduced with increasing levels of albumen.

Palmer et al. (1970) studied the effects of heat treatment after thawing on gelation in frozen-defrosted yolk. Temperatures of 45 to 55°C applied for 1 hour reduced viscosity of white-free yolk and commercial plain, sugared, and salted yolks by more than 50%. Temperatures above the 45 to 55°C range resulted in protein coagulation and increased yolk viscosity.

Varadarajulu and Cunningham (1972a, b, c) found that yolk viscosity decreased by approximately 80% with the addition of 10% albumen, and by about 97% when 25% albumen was added. Pasteurization of commercial yolk did not affect viscosity significantly, but pasteurization at 63 to 65°C for 4 minutes of laboratory prepared yolk produced an increase in viscosity that was curvilinear with increasing temperature. Yolk dried in a Buflovak drier was significantly less viscous than that dried in a Rogers drier. Although age of bird significantly affected yolk viscosity, breed had no effect.

Cunningham's (1972) study of the viscosity of diluted egg yolk showed that yolk with 53% solids had a viscosity of 1600 c.p.s. while yolk with 43% solids had a viscosity of only 200 c.p.s. Dilution with water rather than albumen produced no significant differences in viscosity.

MATERIALS AND METHODS

The infertile eggs used for the fresh liquid and frozen yolk studies were collected from caged Leghorn layers housed at the Kansas State University Poultry Farm. Eggs were stored in a commercial size walk-in cooler at 4°C ± 1°C for 5 days before being used. Plain dried yolk and free-flow dried yolk were obtained from Milton G. Waldbaum Co. (Wakefield, Nebraska). Low viscosity dried yolk was obtained from National Egg Products Corp. (Social Circle, Georgia). All dried yolk samples were stored in a commercial size walk-in freezer at -20°C and were thawed at 4°C ± 1°C in a commercial size walk-in cooler for 24 hours before being used.

Egg yolk preparation

Liquid and frozen samples

Egg components were separated using a household hand separator. The yolk was gently rolled on absorbant paper towel to remove adhering albumen and positioned near the towel edge. The vitelline membrane was ruptured and the yolk liquid collected in 3500 ml plastic jugs. Albumen from the same eggs was blended in a Waring blender and approximately 28% (by weight) was incorporated into the yolk using a Kitchen Aid mixer, Model K45SS, (Hobart Corp., Troy, Ohio) with a wire whip attachment set at speed 1 for 2 minutes. Solids content of the yolk was determined by the overnight atmospheric oven method (Gorman, 1977) to verify that the solids content had been reduced to the commercially required 43%.

Liquid yolk samples The diluted yolk was divided into 160 g samples and treated with iodized NaCl, uniodized NaCl, or KCl (No Salt, Norcliff Thayer, Inc., Tuckahoe, New York). Each type of salt was added at the 5, 10, and 15% levels. One sample containing 0% salt was also prepared. A Kitchen Aid mixer, Model K45SS, with wire whip attachment was used to incorporate the salt. All samples, including the 0% salt, were mixed at speed 1 for 1 minute, the beater was stopped and the bowl scraped down, and mixing was then resumed at speed 1 for an additional 1.5 minutes. The finished samples were stored in 16 oz. plastic screw-top sample jars (Nalgene) at 4°C for not more than 24 hours. Samples were allowed to sit at room temperature (27°C $\pm$ 1°C) for at least 1 hour before testing.

Frozen yolk samples Approximately 1000 ml of prepared yolk was weighed into the bowl of the Kitchen Aid mixer. Ten % iodized NaCl was incorporated into the yolk by mixing with the wire whip at speed 1 for 1 minute, stopping the mixer, scraping the bowl, and mixing an additional 1.5 minutes at speed 1. Fifty g samples of the salted yolk were weighed into 75 ml screw-top glass sample jars and the jars were capped. The jars were then placed in a household type upright freezer at -10°C $\pm$ 2°C. Four jars (200 ml total) were stored for each of 30, 60, and 90 days. Four jars were placed in the freezer for 24 hours and were then removed and tested. Those samples were labeled 0 days frozen storage. Frozen samples were placed in a water bath at 37°C $\pm$ 1°C for 30 minutes, then allowed the stand at room temperature (27°C $\pm$ 1°C) for 20 minutes before testing.

Dried yolk samples

Rehydration of the yolk samples was accomplished using a Kitchen Aid mixer, Model K45SS, with a wire whip attachment. One hundred and fifty g of dried yolk and 190 g of distilled water were weighed into the bowl. The contents were then mixed at speed 1 for 1 minute, the mixer was stopped and the bowl scraped, and mixing was resumed at speed 1 for an additional 1 minute. The weight of rehydrated yolk was determined and 10% iodized NaCl was then incorporated by mixing at speed 1 for 1 minute, stopping the mixer and scraping the bowl, and then mixing at speed 1 for additional 1.5 minutes. The rehydrated, salted yolk samples were placed in 1 qt. Mason jars which were kept capped while tests were being conducted.

Emulsification capacity

A modification of the procedure described by Young et al. (1983) was used to determine emulsification capacity. Fifteen g of salted yolk and 20 ml of 5% acetic acid were mixed in an Osterizer blender for 10 seconds at speed 12. Twenty ml of soybean oil (Wesson) were added and the mixture blended for 20 seconds. More oil was then added dropwise from a 100 ml graduated burette until a sudden drop in viscosity occurred, indicating a "broken" emulsion. The quotient obtained by dividing the total amount of oil (the oil added from the burette plus the original 20 ml) by the g of yolk was taken as the emulsification capacity.

Viscosity

Viscosity of the salted yolk samples was determined at room temperature (27°C $\pm$ 1°C) with a Brookfield RVF Model Syncro-lectric Viscometer. Conditions were spindle 5 and 20 r.p.m. for all liquid yolk samples and for the 0 days frozen storage, spindle 7 and 10 r.p.m. for the 30, 60, and 90 frozen storage, and spindle 7 and 4 r.p.m. for all dried samples. Measurements were corrected and reported as centipoise.

Mayonnaise preparation and testing

Mayonnaise was prepared using a modification of the formula and procedure described by Miller and Winter (1950). The mayonnaise formula consisted of:

Salted egg yolk	16.0 g
Vinegar (5% acetic acid)	30.0 ml
Sugar	3.0 g
Dry mustard (McCormick)	1.0 g
Soybean oil (Wesson)	237.0 ml

The yolk, sugar, mustard, and 10 ml of vinegar were mixed for 0.5 minutes in a Kitchen Aid mixer, Model K45SS, set at speed 8. Forty ml of oil were then added from a 100 ml graduated burette over a 6 minute period, followed by the addition of 10 ml of vinegar in 0.5 minutes. Mixing was continued for 0.5 minutes without the addition of ingredients. The beater was shut off, and the mixture was allowed to rest for 1 minute. After scraping down the bowl, beating was resumed at speed 8, and the remaining 197 ml of oil were added from a 500 ml separatory funnel over a 6 minute period. The final 10 ml of vinegar were added in 1 minute. After scraping down the bowl, the emulsion was mixed on speed 1 for 0.5 minutes. The finished mayonnaise was transferred to a ½ pint Mason jar using a funnel, and the jars were capped and allowed to stand at room temperature (27°C ± 1°C) for 20 to 24 hours before testing.

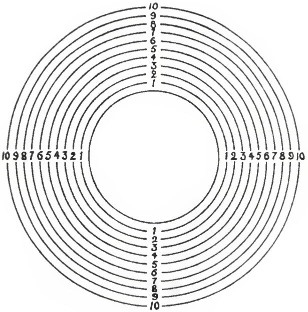
Apparent mayonnaise viscosity was determined at room temperature (27°C $\pm$ 1°C) by a Brookfield RVF Model Syncro-lectric Viscometer (spindle 7, 4 r.p.m.). Results were corrected and reported in centipoise. Spread of mayonnaise was determined by the line spread test described by Grawemeyer and Pfund (1943) and Griswold (1962). In this test, a diagram such as that shown in Figure 2 was placed beneath a level glass plate. Each numbered circle was separated by 3.175 mm. A metal cylinder (22.225 mm high) with an inside diameter of 50.800 mm was placed directly over the smallest circle, filled with sample, and leveled off with a spatula. The cylinder was carefully lifted off and the mayonnaise was allowed to spread for 2 minutes. After the spread period, readings were taken at 4 widely separated points representing the limits reached by the mayonnaise. The average of the 4 readings was taken as the number of 3.175 mm units the mayonnaise spread at room temperature in 2 minutes.

Stability of the mayonnaise was determined by incubating the samples at 40°C $\pm$ 1°C until the emulsion broke. A broken emulsion was taken as the point at which oil became visible at the top of the emulsion, giving the mayonnaise a "curdled" appearance. Stability was recorded as the days at 40°C required for an emulsion to break.

Standard plate counts (standard plate count agar) were performed before and after incubation to determine if a significant increase in bacteria occurred. Mold and yeast counts (potato dextrose agar) were also performed before and after incubation to determine if a significant increase in mold or yeast occurred.

Data were statistically analyzed by analysis of variance and by Duncan's Multiple Range Test.

FIGURE 2. Diagram of concentric circles used beneath a glass plate to measure line spread.


10 9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9 10

RESULTS AND DISCUSSION

LIQUID YOLK

Viscosity

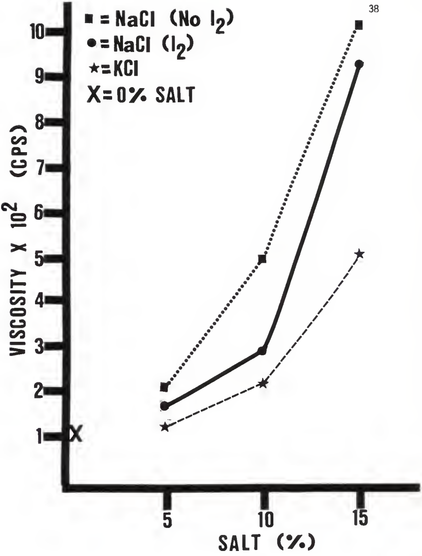
The effects of salt type and level on viscosity of liquid yolk are illustrated in Figure 3, while the corresponding treatment means are shown in Table 3 (Appendix).

Salt type was found to have a significant (P>0.05) effect on viscosity of liquid yolk. Table 4 (Appendix) shows the viscosity means for each of the 3 salts. Uniodized NaCl caused the largest increase in viscosity, while KCl produced the least increase. Iodized NaCl caused an intermediate increase in viscosity.

Salt level was also found to have a significant (P>0.05) effect on viscosity of liquid yolk. Table 5 (Appendix) shows the viscosity means for each of the 3 levels. The 5% level produced the least increase in viscosity, the 10% level caused an intermediate increase, and the 15% level produced the largest viscosity increase.

The increase in the viscosity of liquid yolk upon the addition of NaCl has also been reported by Jordan and Whitlock (1955), Scalzo et al. (1970), and Johnson (1970). Jordan and Whitlock (1955) hypothesized that NaCl added to yolk tended to cause the lipovitellin to take up water which in turn increased the particle size with a consequent increase in apparent viscosity. The differences in viscosity due to the salts used in this study might be explained in terms of the effects of solutes on water. Bone (1973) stated that "When a solute is added to water, several things happen. First, the concentration of water is reduced, and second, the interaction of the solute

FIGURE 3. Illustration of the influence of salt type and level on viscosity of liquid yolk.


■ = NaCl (No I_2)
● = NaCl (I_2)
★ = KCl
X = 0% SALT
VISCOSITY X 10^2 (CPS)
1
2
3
4
5
6
7
8
9
10
X
5
10
15
SALT (%)

with the water may break or increase the water structure." Ions which are small and/or multivalent, such as Na^+, tend to have strong electric fields and are considered net structure formers (Fennema, 1976). Large and monovalent ions, including K^+, Cl^-, and I^-, tend to disrupt the normal water structure and are termed net structure breakers (Fennema, 1976). The 3 salts tested in this experiment all provided Cl^- ions. The differences in yolk viscosity increases between the 3 salts, therefore, could be due to the Na^+, K^+, and I^- ions. The addition of any of the salts would theoretically cause dehydration of the egg proteins. When the uniodized NaCl was used, the strong net structure forming ability of the Na^+ ion would compensate for the extra water split off by dehydration by binding with that water. With the loss of the water to the Na^+, the dehydrated proteins would be able to associate, and the large protein aggregate thus formed would then cause the increased viscosity. The difference between the uniodized and iodized NaCl could possibly be attributed to the I^- ion. The iodized NaCl would provide 2 structure breaking ions (Cl^- and I^-), which would result in less of the extra water being bound. Although the dehydrated proteins would still aggregate, the increased amount of unstructured water would result in less of a viscosity increase. Since both ions from the KCl tend to be structure breakers, the extra water from the dehydrated proteins would be even less structured than with either of the NaCl salts, resulting in the lower viscosity increase.

A noticeable change in yolk color occurred upon addition of any of the 3 salts. Yolk containing either iodized or uniodized NaCl became dark yellow, while yolk containing KCl became a deep yellow-orange color. This change in yolk color produced no noticeable difference in mayonnaise color.

Jordan and Whitlock (1955) and Jaax and Travnicek (1968) also reported a darkening in yolk color upon addition of NaCl.

Emulsification capacity

The effects of salt type and level on liquid yolk emulsification capacity are illustrated in Figure 4, while the corresponding treatment means are shown in Table 6 (Appendix).

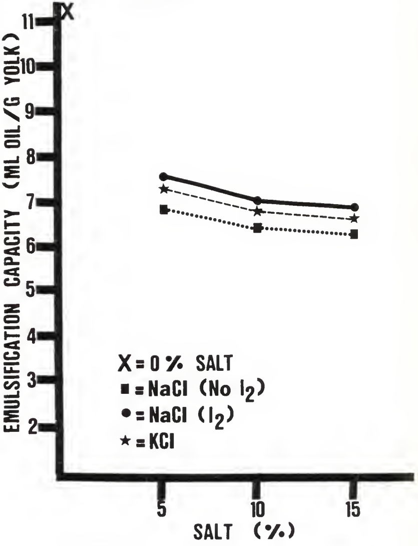
The emulsification capacity of the 0% salt sample was 11.25. This is comparable to the value of 11.10 $\pm$ 0.39 reported by Young et al. (1983). The addition of any of the 3 salts at even the 5% level was found to dramatically reduce the emulsification capacity of the liquid yolk.

Table 7 (Appendix) shows the treatment means for the effect of salt type on emulsification capacity of liquid yolk. No significant ($P>0.05$) differences in emulsification capacity between yolk treated with iodized NaCl and that treated with KCl were found at any of the 3 levels of salt addition. Uniodized NaCl caused a significant ($P>0.05$) decrease in emulsification capacity with a mean of 6.53.

Table 8 (Appendix) shows the treatment means for the effect of salt level on emulsification capacity of liquid yolk. Salt level was found to have a significant ($P>0.05$) effect on emulsification capacity. The 5% level caused the least reduction in emulsification capacity, followed by the 10% level. The 15% level caused the greatest reduction in emulsificaton capacity.

The emulsifying properties of egg yolk are due to the presence of protein and lipoprotein complexes (Sell et al., 1935). As suggested earlier, the addition of NaCl or KCl probably caused a dehydration of those complexes, which in turn could influence their emulsifying properties. This

FIGURE 4. Illustration of the influence of salt type and level on emulsification capacity of liquid yolk.


EMULSIFICATION CAPACITY (ML OIL/G YOLK)
11
10
9
8
7
6
5
4
3
2
X
X = 0 % SALT
■ = NaCl (No I_2)
● = NaCl (I_2)
★ = KCl
5
10
15
SALT (%)

might account for the decrease in emulsification capacity of the liquid yolk upon the addition of the 3 salts.

Mayonnaise tests

The effects of salt type and level on apparent mayonnaise viscosity are illustrated in Figure 5, while the corresponding treatment means are shown in Table 9 (Appendix). The effects of salt type and level on mayonnaise spread are illustrated in Figure 6, with the corresponding treatment means being shown in Table 10 (Appendix).

Analysis of the Brookfield viscometer data indicated that salt type had a significant (P>0.05) effect on apparent mayonnaise viscosity (Table 11, Appendix). Mayonnaise made with KCl had the lowest apparent viscosity at each of the 3 levels, followed by mayonnaise made with uniodized NaCl. Mayonnaise made with iodized NaCl had the highest apparent viscosity at each of the 3 levels.

Analysis of variance of the line spread data indicated that there was no significant (P>0.05) difference in spread between mayonnaise made with uniodized NaCl and that made with KCl (Table 12, Appendix). Further analysis by Duncan's Multiple Range Test (Table 10, Appendix) showed that this was true only at the 5 and 15% levels. At the 10% level, Duncan's Multiple Range Test indicated that there was no significant (P>0.05) difference in spread between mayonnaise made with KCL and that made with iodized NaCl.

Salt level had a significant (P>0.05) effect on both apparent viscosity and spread of mayonnaise (Tables 13 and 14, Appendix). Overall, mayonnaise with 10% salt had the highest mean Brookfield viscosity value, and the

FIGURE 5. Illustration of the influence of salt type and level on apparent mayonnaise viscosity.

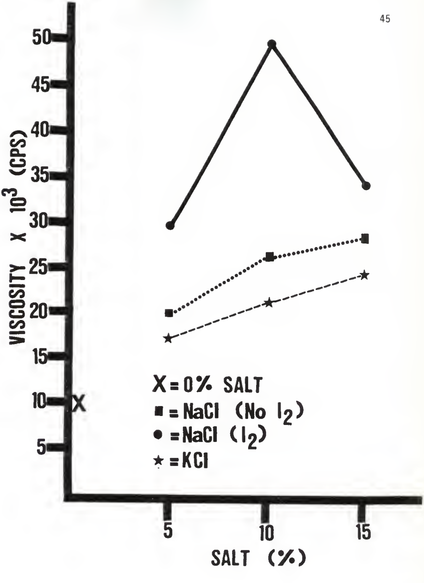
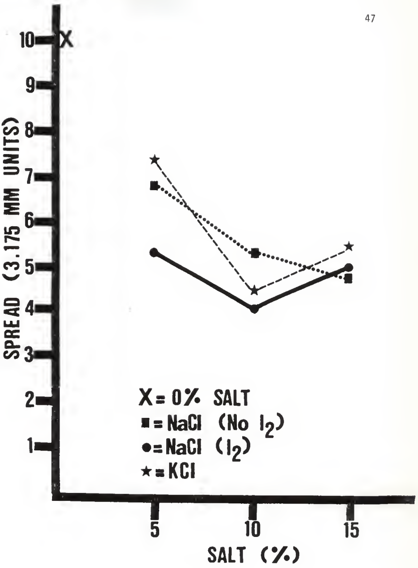

VISCOSITY X 10³ (CPS)
50
45
40
35
30
25
20
15
10
5
X
X = 0% SALT
■ = NaCl (No I₂)
● = NaCl (I₂)
★ = KCl
5
10
15
SALT (%)

FIGURE 6. Illustration of the influence of salt type and level on mayonnaise spread.


SPREAD (3.175 MM UNITS)
SALT (%)
X = 0% SALT
■ = NaCl (No I_2)
● = NaCl (I_2)
★ = KCl
10
9
8
7
6
5
4
3
2
1
5
10
15
X

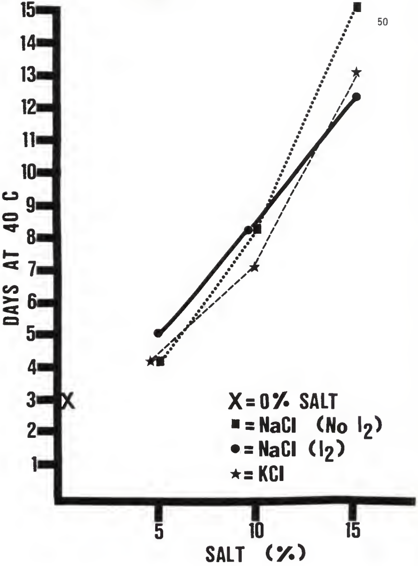
lowest mean spread; mayonnaise with 15% salt had an intermediate mean Brookfield viscosity value as well as an intermediate mean spread, and mayonnaise with 5% salt had the lowest mean Brookfield viscosity value and the highest mean spread. A general trend was observed with mayonnaise made with either KCl or uniodized NaCl. As the level of either of those salts was increased from 5 to 15%, apparent viscosity of the mayonnaise increased. Iodized NaCl did not follow this trend however; the large increase in apparent viscosity which occurred in mayonnaise made with 10% iodized NaCl was followed by a decrease in apparent viscosity for mayonnaise made with 15% iodized NaCl. The reason for this increase/decrease is not known.

The effects of salt type and level on mayonnaise stability are illustrated in Figure 7, while the corresponding treatment means are shown in Table 15 (Appendix).

Both salt type and salt level were found to effect mayonnaise stability (Tables 16 and 17, Appendix). Overall, uniodized NaCl produced mayonnaise with the highest mean stability, followed by iodized NaCl. KCl produced mayonnaise with the lowest mean stability. Mayonnaise containing 15% salt had the highest mean stability at 13.4 days, followed by 10% salt at 7.9 days, and 5% salt at 4.6 days.

When the 3 salts were compared at each of the 3 levels, no significant ($P>0.05$) difference in stability was found at the 5% level for any of the salts. There was no significant ($P>0.05$) difference in stability between mayonnaise made with 10% uniodized NaCl and that made with 10% iodized NaCl, but mayonnaise made with 10% KCl had a significantly ($P>0.05$) lower stability. At the 15% level, though, there was no significant ($P>0.05$) difference in stability of mayonnaise made with KCl or iodized NaCl, but

FIGURE 7. Illustration of the influence of salt type and level on mayonnaise stability.


DAYS AT 40 C
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
X
X = 0% SALT
■ = NaCl (No I2)
● = NaCl (I2)
★ = KCl
5
10
15
SALT (%)

mayonnaise made with 15% uniodized NaCl had a significantly (P>0.05) higher stability.

Krantz and Gordon (1928) found that NaCl stabilized some emulsions. In work conducted with emulsions stabilized by casein, Seifriz (1935) found that NaCl tended to stabilize oil-in-water emulsions, but had no influence on water-in-oil emulsions. Lowe (1955) suggested that the effect of NaCl on emulsion stability would probably depend on both the emulsifier and the concentration of the NaCl. Data from this study showed that addition of any of the salts at even the 5% level resulted in a significant (P>0.05) increase in stability over mayonnaise made with 0% salt. Lowe (1955) also found that salt (NaCl) increased mayonnaise stability.

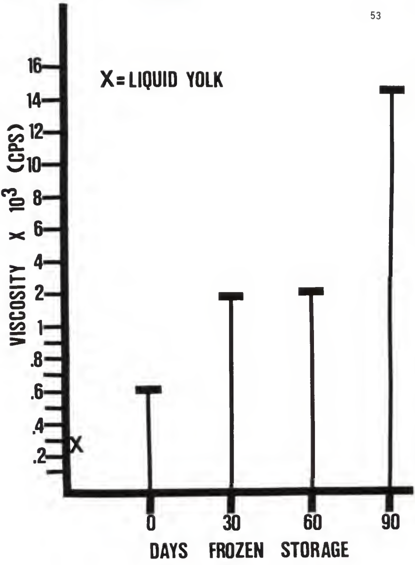
FROZEN YOLK

Viscosity

The effect of frozen storage time on salted yolk apparent viscosity is illustrated in Figure 8, while the corresponding treatment means are shown in Table 18 (Appendix).

Storage of salted yolk at -10°C for even 24 hours (0 days) was found to result in a considerable increase in apparent viscosity over fresh salted yolk. Apparent viscosity of salted yolk stored 30 days was approximately three times greater than that stored 24 hours. There was no significant (P>0.05) difference, though, between yolk stored 30 and 60 days. Yolk stored at -10°C for 90 days had a significantly (P>0.05) higher apparent viscosity than any other treatment. Palmer et al. (1969a) also reported increases in viscosity of 10% salted yolk stored at -10°F over a period of 4 months. Powrie et al. (1963) suggested that viscosity changes in thawed yolk under

FIGURE 8. Illustration of the influence of frozen storage time on apparent viscosity of salted yolk.


X = LIQUID YOLK
VISCOSITY X 10^3 (CPS)
16
14
12
10
8
6
4
2
1
.8
.6
.4
.2
X
0
30
60
90
DAYS FROZEN STORAGE

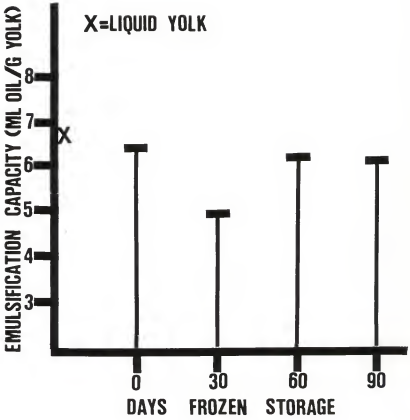
conditions of constant thawing rate were the result of protein structural alterations occurring in the frozen state of yolk. Davey et al. (1969) suggested that increased apparent viscosity of the lipovitellenin fraction after freezing was the basis for increased viscosity of frozen native yolk.

Emulsification capacity

The effect of frozen storage time on emulsification capacity of salted yolk is illustrated in Figure 9, with the corresponding treatment means being shown in Table 19 (Appendix).

Storage of salted yolk at -10°C for 24 hours (0 days) resulted in a reduction in emulsification capacity to 6.39 from 6.85 for fresh liquid yolk with 10% iodized NaCl. Storage at -10°C for 60 days reduced the emulsification capacity to 6.10, which was not significantly ($P>0.05$) different from the emulsification capacity of 6.06 for yolk stored 90 days. Thirty days of frozen storage resulted in yolk with the lowest emulsification capacity at 5.92, but this was not significantly ($P>0.05$) different from yolk stored 90 days. Freezing of biological materials such as egg yolk results in pure water being removed to form ice crystals (Meryman, 1956). This causes dehydration of the proteins, and an increase in the concentration of salts (Powrie et al., 1963). Powrie et al. (1963) further suggested that the consequent changes in water structure due to dehydration and salt concentration increase could allow for rearrangement and aggregation of the yolk lipoproteins. This rearrangement and aggregation could influence the emulsification capacity of the yolk. The reason why emulsification capacity decreased during the first 30 days of frozen storage, increased during the

FIGURE 9. Illustration of the influence of frozen storage time on emulsification capacity of salted yolk.



X=LIQUID YOLK
EMULSIFICATION CAPACITY (ML OIL/G YOLK)
8
7
6
5
4
3
X
0
30
60
90
DAYS FROZEN STORAGE

second 30 days, and then decreased slightly during the last 30 days of frozen storage, though, is unclear.

Mayonnaise tests

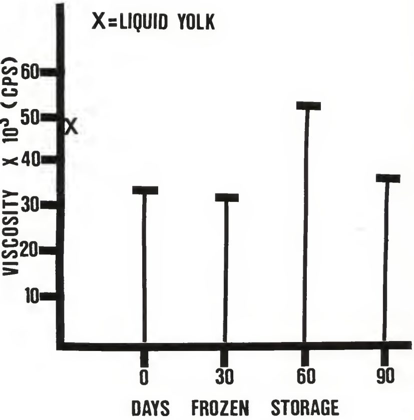
The effect of frozen storage time on apparent mayonnaise viscosity is illustrated in Figure 10, while the corresponding treatment means are shown in Table 20 (Appendix). The effect of frozen storage time on mayonnaise spread is illustrated in Figure 11, with the corresponding treatment means being shown in Table 21 (Appendix).

Mayonnaise made from yolk stored at -10°C for 60 days had a significantly (P>0.05) higher apparent viscosity than that made from any other frozen yolk sample. No significant (P>0.05) difference in apparent viscosity was found between mayonnaise made from yolk stored 0, 30, or 90 days. Line spread data showed that yolk stored 60 days produced mayonnaise with a significantly (P>0.05) lower spread than any other sample. No significant (P>0.05) difference in spread was found between mayonnaise made from yolk stored 0, 30, or 90 days. Both apparent viscosity and spread of mayonnaise made from 60 day frozen yolk were comparable to the apparent viscosity and spread of mayonnaise made from fresh liquid yolk containing 10% iodized NaCl.

The effect of frozen storage time on stability of mayonnaise is illustrated in Figure 12, while the corresponding treatment means are shown in Table 22 (Appendix).

Storage of yolk at -10°C for 24 hours resulted in a mean stability of 22 days. This is a dramatic increase over the 8.3 days determined for fresh liquid salted yolk. Subsequent storage of yolk at -10°C for 30, 60, and 90

FIGURE 10. Illustration of the influence of frozen storage time on apparent mayonnaise viscosity.



X=LIQUID YOLK
VISCOSITY X 10^3 (CPS)
60
50
40
30
20
10
X
0
30
60
90
DAYS FROZEN STORAGE

FIGURE 11. Illustration of the influence of frozen storage time on mayonnaise spread.

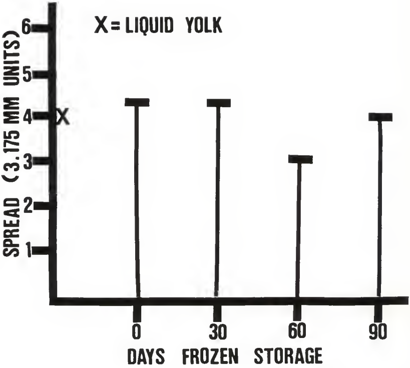
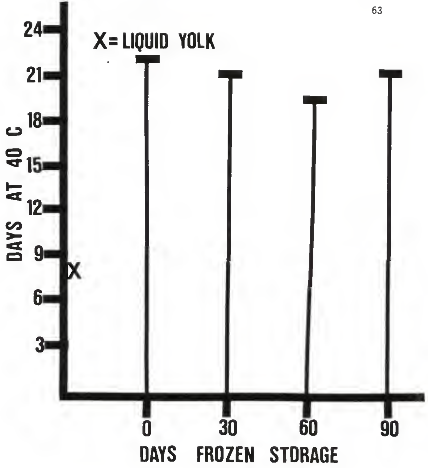

X = LIQUID YOLK
SPREAD (3.175 MM UNITS)
6
5
4
X
3
2
1
0
30
60
90
DAYS FROZEN STORAGE

FIGURE 12. Illustration of the influence of frozen storage time on mayonnaise stability.


X = LIQUID YOLK
DAYS AT 40 C
24
21
18
15
12
9
6
3
X
0
30
60
90
DAYS FROZEN STORAGE

days produced mayonnaise with mean stabilities of 21, 20, and 21 days respectively.

YOLK SOLIDS

Viscosity

Apparent viscosity of the 3 types of yolk solids is illustrated in Figure 13, with the corresponding treatment means being shown in Table 23 (Appendix).

All 3 types of yolk solids were found to have a dramatically higher apparent viscosity than either liquid or frozen yolk. There was a significant (P>0.05) difference in apparent viscosity between all 3 types of yolk solids; free flow yolk solids had the highest apparent viscosity at 627,200 c.p.s., followed by plain yolk solids at 501,200 c.p.s. Low viscosity yolk solids had the lowest apparent viscosity at 172,400 c.p.s. Varadarajulu and Cunningham (1972) also found that spray dried yolk had a greater apparent viscosity than fresh yolk.

Emulsification capacity

Emulsification capacity for the 3 types of yolk solids is illustrated in Figure 14, while the corresponding treatment means are shown in Table 24 (Appendix).

All 3 types of yolk solids had a considerably lower emulsification capacity than fresh yolk containing 10% iodized NaCl. No significant (P>0.05) difference was found in emulsification capacity between plain yolk solids and free flow yolk solids. Low viscosity yolk solids had a significantly (P>0.05) lower emulsification capacity at 6.02. These results agree with those of

FIGURE 13. Illustration of the apparent viscosity of the 3 types of yolk solids.
X = liquid yolk, P = plain yolk solids,
F = free flow yolk solids, L = low viscosity yolk solids.

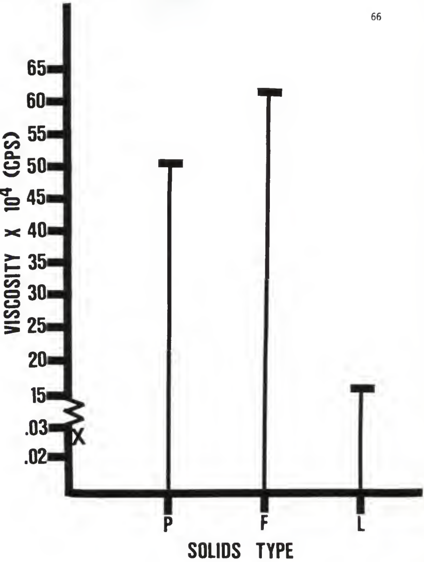
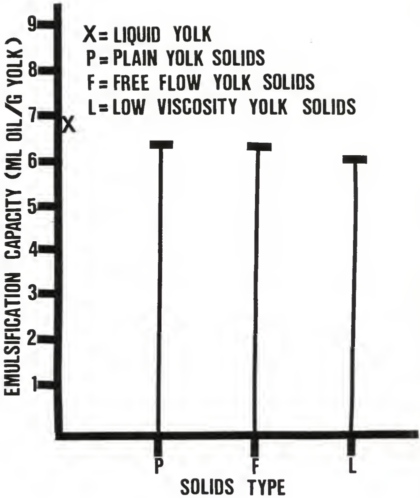

VISCOSITY x 10^4 (CPS)
65
60
55
50
45
40
35
30
25
20
15
.03
.02
X
P
F
L
SOLIDS TYPE

FIGURE 14. Illustration of the emulsification capacity of the 3 types of yolk solids.


X = LIQUID YOLK
P = PLAIN YOLK SOLIDS
F = FREE FLOW YOLK SOLIDS
L = LOW VISCOSITY YOLK SOLIDS
EMULSIFICATION CAPACITY (ML OIL/G YOLK)
9
8
7
6
5
4
3
2
1
X
P
F
L
SOLIDS TYPE

Rolfes et al. (1955), who found that lyophilization impaired yolk emulsifying properties, and Zabik (1969) and Varadarajulu and Cunningham (1972), who found that spray drying altered the emulsifying properties of the yolk. Schultz et al. (1966) reported that a rapid increase in extractability of "free lipids" during drying was extremely detrimental to the emulsifying function of the yolk.

Mayonnaise tests

Apparent viscosity of mayonnaise made from each of the 3 types of yolk solids is illustrated in Figure 15, with the corresponding treatment means being shown in Table 25 (Appendix). Spread of mayonnaise made from each of the 3 types of yolk solids is illustrated in Figure 16, while the corresponding treatment means are shown in Table 26 (Appendix). Apparent viscosity was significantly (P>0.05) different for mayonnaise made from each yolk sample; mayonnaise made from low viscosity solids had the highest apparent viscosity at 38,250 c.p.s., followed by plain yolk solids mayonnaise at 29,500 c.p.s., and free flow yolk solids mayonnaise at 23,000 c.p.s. No significant (P>0.05) difference in spread was found between mayonnaise made from any of the yolk solids samples.

Observation during the initial stage of mayonnaise formation indicated that yolk solids did not foam as much as either liquid or frozen yolk. These observations agree with the results of Schultz et al. (1966), who reported that egg yolk which is dried and subsequently rehydrated loses it's foaming ability. Mayonnaise made from yolk solids was also darker yellow in color and had less volume than that made from either liquid or frozen yolk.

FIGURE 15. Illustration of the apparent viscosity of mayonnaise made from the 3 types of yolk solids.

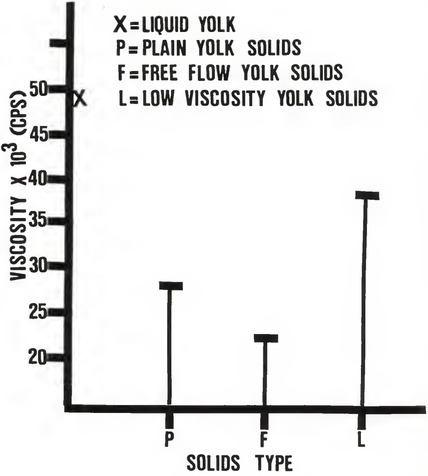
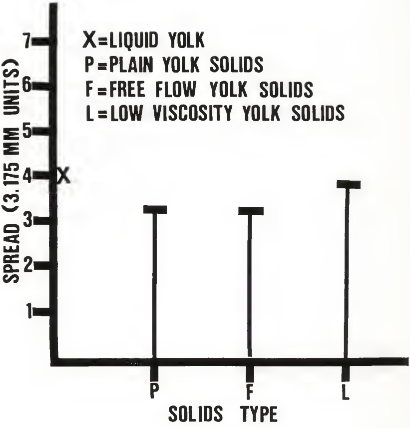

X = LIQUID YOLK
P = PLAIN YOLK SOLIDS
F = FREE FLOW YOLK SOLIDS
L = LOW VISCOSITY YOLK SOLIDS
VISCOSITY X 10^3 (CPS)
50
45
40
35
30
25
20
X
P
F
L
SOLIDS TYPE

FIGURE 16. Illustration of the spread of mayonnaise made from the 3 types of yolk solids.


X=LIQUID YOLK
P=PLAIN YOLK SOLIDS
F=FREE FLOW YOLK SOLIDS
L=LOW VISCOSITY YOLK SOLIDS
SPREAD (3.175 MM UNITS)
1
2
3
4
5
6
7
X
P
F
L
SOLIDS TYPE

Stability values for mayonnaise made from the 3 types of yolk solids are illustrated in Figure 17, while the corresponding treatment means are shown in Table 27 (Appendix).

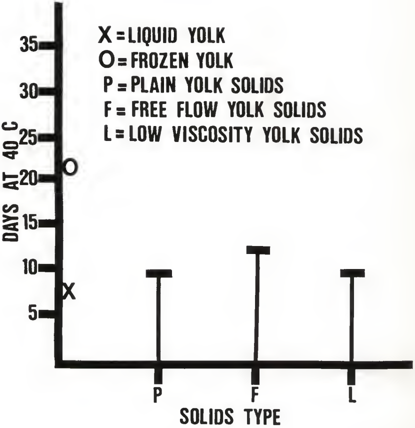
Mayonnaise made from free flow yolk solids had the highest stability at 12 days. Mayonnaise made from plain yolk solids and from low viscosity yolk solids had stabilities of 10 days. These values are approximately intermediate between stability values determined for mayonnaise made from frozen yolk (highest overall stability) and liquid yolk (lowest overall stability).

MAYONNAISE MICROBIOLOGY

Microbial counts before and after incubation for all mayonnaise samples are shown in Table 28.

Standard plate counts before and after incubation of mayonnaise made from either the liquid or frozen samples resulted in a general trend - except for the 15% iodized NaCl, the number of colony forming units was less after incubation than before. This is probably attributable to the combination of heat, acid, and salt present during incubation. Standard plate counts on mayonnaise made from yolk solids showed an increase in the number of colony forming units after incubation. Differences in mold and yeast counts before and after incubation were relatively slight for all mayonnaise samples.

FIGURE 17. Illustration of the stability of mayonnaise made from the 3 types of yolk solids.


X = LIQUID YOLK
O = FROZEN YOLK
P = PLAIN YOLK SOLIDS
F = FREE FLOW YOLK SOLIDS
L = LOW VISCOSITY YOLK SOLIDS
DAYS AT 40 C
35
30
25
20
15
10
5
X
O
P
F
L
SOLIDS TYPE

REFERENCES

Anonymous. 1983. Grinsted Emulsifiers for Food. Grinsted Products, Inc., 201 Industrial Parkway, Industrial Airport, Kansas City, Kansas 66031.

Baldwin, R. E. 1977. Functional properties in foods. In Egg Science and Technology. W. J. Stadelman and O. J. Cotterill (eds). AVI Publishing Company, Inc. Westport, Conn.

Becher, P. 1957. Emulsions: Theory and Practice. Van Nostrand Reinhold Publishing Company. New York, New York.

Bennett, H. 1947. Practical Emulsions. 2nd ed. Chemical Publishing Company, Inc. Brooklyn, New York.

Berger, K. G. 1976. Ice cream. In Food Emulsions. S. Friberg (ed.) Marcel Dekker, Inc. New York, New York.

Bone, D. 1973. Water activity in intermediate moisture foods. Food Tech. 27:71-76.

Brown, L. C. 1949. Emulsion food products. J. Am. Oil Chem. Soc. 10:632-636.

Carlin, A. F. 1955. Relation of acid to the emulsifying action of dried yolk in the preparation of mayonnaise. Poultry Sci. 34:1186-1187 (abs).

Chang, P. K., W. D. Powrie, and O. Fennema. 1970. Effect of heat treatment on viscosity of yolk. J. Food Sci. 35:864-867.

Chapin, R. 1951. Some factors affecting emulsifying properties of hens' egg. Ph.D Thesis. Iowa State College. Ames, Iowa.

Clayton, W. 1928. The Theory of Emulsions and Their Technical Treatment. 2nd ed. P. Blakiston's Son and Company. Philadelphia, Penn.

Clayton, W., and J. T. Morse. 1939. Direct observation of emulsification. Chem. and Ind. 17:304-305.

Corran, J. W. 1943. Some observations on a typical food emulsion. In Emulsion Technology: Theoretical and Applied. H. Bennett (ed). Chemical Publishing Company, Inc. New York, New York.

Corran, J. W., and C. N. Lewis. 1924. Lecithin and cholesterol in relation to the physical nature of cell membranes. Biochem. J. 18:1364-1370.

Cotterill, O. J., J. Glauert, and H. J. Bassett. 1976. Emulsifying properties of salted yolk after pasteurization and storage. Poultry Sci. 55:544-548.

Cunningham, F. E. 1972. Viscosity and functional ability of diluted egg yolk. J. Milk Food Tech. 35:615-617.

Cunningham, F. E. 1975. Influence of added lecithin on properties of hens' egg yolk. Poultry Sci. 54:1307-1308.

Davey, E. M., M. E. Zabik, and L. E. Dawson. 1969. Fresh and frozen egg yolk protein fractions: Emulsion stabilizing power, viscosity, and electrophoretic patterns. Poultry Sci. 48:251-260.

Epstein, A. K. 1937. Commercial mayonnaise. In Mayonnaise and Other Salad Dressings. The Emulsol Corporation. Chicago, Ill.

Fennema, O. 1976. Water and ice. In Principles of Food Science. Part I. Food Chemistry. O. Fennema (ed). Marcel Dekker, Inc. New York, New York.

Finberg, A. J. 1955. Advanced techniques for making mayonnaise and salad dressing. Food Eng. 27:83-91.

Gorman, J. M. 1973. Quality control and product specifications. In Egg Science and Technology. W. J. Stadelman and O. J. Cotterill (eds). AVI Publishing Company, Inc. Westport, Conn.

Graf, E., and H. Bauer. 1976. Milk and milk products. In Food Emulsions. S. Friberg (ed). Marcel Dekker, Inc. New York, New York.

Grawemeyer, E. A., and M. C. Pfund. 1943. Line-spread as an objective test for consistency. Food Res. 8:105-108.

Gray, D. M., and C. A. Southwick, Jr. 1929. Scientific research affords means of measuring stability of mayonnaise. Food Inds. 4:300-304.

Griswold, R. M. 1962. Evaluating food by objective methods. In The Experimental Study of Foods. Houghton Mifflin Company. Boston, Penn.

Hall, I. S., and E. H. Dawson. 1940. Effect of air film in emulsification. Ind. Eng. Chem. 32:415-420.

Jaax, S., and D. Travnicek. 1968. The effect of pasteurization, selected additives, and freezing rate on the gelation of frozen-defrosted egg yolk. Poultry Sci. 47:1013-1022.

Johnson, P. I. 1970. Functional performance and selected chemical and physical properties of frozen egg yolk containing various additives. M.S. Thesis. Kansas State University. Manhattan, Kansas.

Jordan, R., and E. S. Whitlock. 1955. A note on the effect of salt (NaCl) upon the apparent viscosity of egg yolk, egg white, and whole egg magma. Poultry Sci. 34:566-571.

Jordan, R., G. E. Vail, J. C. Rogler, and W. J. Stadelman. 1962. Further studies on eggs from hens on diets differing in fat content. Food Tech. 6:118-120.

Kilgore, L. B. 1932. The mustard and the mayonnaise. Flavor ingredient has important effect on stability of the emulsion. Glass Packer. 10:621-623.

Kilgore, L. B. 1933a. The mustard and the mayonnaise. Effects on permanency, stability, and consistency. Glass Packer. 2:97-99.

Kilgore, L. B. 1933b. Observations on the proper amount of yolk in mayonnaise. U.S. Egg and Poultry Mag. 39:42-45, 63.

Kilgore, L. B. 1934. Testing mustard for mayonnaise. Glass Packer. 2:114-116, 126.

Kilgore, L. B. 1935. Egg yolk "makes" mayonnaise. Food Inds. 7:229-230.

King, A. 1941. Some factors governing the stability of oil-in-water emulsions. Trans. Faraday Soc. 37:168-180.

Krantz, J. C., Jr., and N. E. Gordon. 1928. Emulsions and the effect of hydrogen ion concentration upon their stability. Colloid Symposium Monograph. 6:173-206.

Lopez, A., C. A. Fellers, and W. D. Powrie. 1954. Some factors affecting gelation of frozen egg yolk. J. Milk Food Tech. 17:334-339.

Lowe, B. 1955. Emulsions. In Experimental Cookery From the Chemical and Physical Standpoint. John Wiley and Sons, Inc. New York, New York.

Lynch, M. J., and W. C. Griffin. 1974. Food emulsions. In Emulsions and Emulsion Technology. Part I. K. Lissant (ed). Marcel Dekker, Inc. New York, New York.

Marion, W. W., and W. J. Stadelman. 1958. An investigation of the gelation of thawed egg yolk. Poultry Sci. 37:1224 (abs).

Mark, K. L. 1921. Emulsification in mayonnaise. J. Home Ec. 13:447 (abs).

Meryman, H. T. 1956. Mechanics of freezing living cells and tissues. Science. 24:515-521.

Meyer, D. D., and M. Woodburn. 1965. Gelation of frozen-defrosted egg yolk as affected by selected additives: Viscosity and electrophoretic findings. Poultry Sci. 44:437-446.

Miller, C., and A. R. Winter. 1950. Pasteurized frozen whole egg and yolk for mayonnaise production. Food Res. 16:43-49.

Palmer, H. H., K. Ijichi, S. L. Cimino, and H. Roff. 1969a. Salted egg yolks. 1. Viscosity and performance of pasteurized and frozen samples. Food Tech. 23:148-153.

Palmer, H. H., K. Ijichi, S. L. Cimino, and H. Roff. 1969b. Salted egg yolks. 2. Viscosity and performance of acidified, pasteurized, and frozen samples. Food Tech. 23:154-156.

Palmer, H. H., K. Ijichi, and H. Roff. 1970. Partial thermal reversal of gelation in thawed egg yolk products. J. Food Sci. 35:403-406.

Pankey, R. D., and W. J. Stadelman. 1969. Effect of dietary fats on some chemical and functional properties of eggs. J. Food Sci. 34:312-317.

Payawal, S. R., B. Lowe, and G. T. Stewart. 1946. Pasteurization of liquid egg products. 2. Effects of heat treatment on appearance and viscosity. Food Res. 11:246-260.

Pearce, J. A., and C. G. Lavers. 1949. Liquid and frozen egg. V. Viscosity, baking quality, and other measurements on frozen egg products. Can. J. Res. 27:231-240.

Powrie, W. D. 1977. Chemistry of eggs and egg products. In Egg Science and Technology. W. J. Stadelman and O. J. Cotterill (eds). AVI Publishing Company, Inc. Westport, Conn.

Powrie, W. D., and M. A. Tung. 1976. Food dispersions. In Principles of Food Science. Part I. Food Chemistry. O. Fennema (ed). Marcel Dekker, Inc. New York, New York.

Powrie, W. D., H. Little, and A. Lopez. 1963. Gelation in egg yolk. J. Food Sci. 28:38-46.

Preston, B. 1983. Personal communication.

Robinson, S. K. 1924. Practice in mayonnaise manufacture. Am. Food J. 19:185-187.

Rolfes, T., P. Clements, and A. R. Winter. 1955. The physical and functional properties of lyophilized whole egg, yolk, and white. Food Tech. 9:569-572.

Scalzo, A. M., R. W. Dickerson Jr., J. T. Peeler, and R. B. Read, Jr. 1970. The viscosity of egg and egg products. Food Tech. 24:113-119.

Schultz, J. R., H. E. Snyder, and R. H. Forsythe. 1966. Interactions of carbohydrates with egg lipoproteins. Poultry Sci. 45:1122 (abs).

Schut, Y. 1976. Meat emulsions. In Food Emulsions. S. Friberg (ed). Marcel Dekker, Inc. New York, New York.

Seifriz, W. 1925. Studies on emulsions I, II, III, IV, V, VI, VII, VIII. J. Phys. Chem. 29:587-600, 738-749, 834-841.

Sell, H. M., A. G. Olsen, and R. E. Kremers. 1935. Lecitho-protein. The emulsifying ingredient in egg yolk. Ind. and Eng. Chem. 27:1222-1223.

Shepard, I. S., and R. W. Yoell. 1976. Cake emulsions. In Food Emulsions. S. Friberg (ed). Marcel Dekker, Inc. New York, New York.

Stadelman, W. J. 1977. Quality identification of shell eggs. In Egg Science and Technology. W. J. Stadelman and O. J. Cotterill (eds). AVI Publishing Company, Inc. Westport, Conn.

Varadarajulu, P., and F. E. Cunningham. 1972a. A study of selected charcteristics of hens' egg yolk. 1. Influence of albumen and selected additives. Poultry Sci. 51:542-546.

Varadarajulu, P., and F. E. Cunningham. 1972b. A study of selected characteristics of hens' egg yolk. 2. Influence of processing procedures, pasteurization, and yolk fractionation. Poultry Sci. 51:941-945.

Varadarajulu, P., and F. E. Cunningham. 1972c. A study of selected characteristics of hens' egg yolk. 3. Influence of breed, strain, and age of bird. Poultry Sci. 51:1327-1331.

Vincent, R., W. D. Powrie, and O. Fennema. 1966. Surface activity of yolk, plasma, and dispersions of yolk fractions. J. Food Sci. 31:643-648.

Weiss, T. 1970. Mayonnaise and salad dressings. In Food Oils and Their Uses. AVI Publishing Company, Inc. Westport, Conn.

Yeadon, D. A., L. A. Goldblatt, and A. M. Altschul. 1958. Lecithin in oil-in-water emulsions. J. Am. Oil Chem. Soc. 35:435-438.

Young, L. L., D. Hamm, and L. C. Blankenship. 1983. Comparison of ova yolk with egg yolk. Poultry Sci. 62:392-394.

Zabik, M. E. 1969. Comparison of frozen, foam-spray-dried, freeze-dried, and spray-dried eggs. 6. Emulsifying properties at three pH levels. Food Tech. 23:130-132.

APPENDIX

TABLE 3. Treatment Means for Egg Yolk Viscosity

Treatment	Mean[1,2] (c.p.s.)
15% uniodized NaCl	1008.0[a]
15% iodized NaCl	932.0[b]
15% KCl	560.0[c]
10% uniodized NaCl	500.0[c]
10% iodized NaCl	288.0[e]
10% KCl	216.0[f]
5% uniodized NaCl	208.0[f]
5% iodized NaCl	168.0[g]
5% KCl	120.0[h]
0% salt	104.0[i]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 5 replications.

TABLE 4. Treatment Means for Effect of Salt Type on Apparent Yolk Viscosity

Treatment	Mean[1] (c.p.s.)
Uniodized NaCl	572.0[a]
Iodized NaCl	462.7[b]
KCl	298.7[c]

[1] Means with the same letter are not significantly different.

TABLE 5. Treatment Means for Effect of Salt Level on Apparent Yolk Viscosity

Treatment	Mean[1] (c.p.s.)
15%	833.3[a]
10%	334.7[b]
5%	165.3[c]

[1] Means with the same letter are not significantly different.

TABLE 6. Treatment Means for Emulsification Capacity

Treatment	Mean[1,2] (ml oil/g yolk)
0% salt	11.25[a]
5% iodized NaCl	7.27[b]
5% KCl	7.22[b]
5% uniodized NaCl	6.92[c]
10% iodized NaCl	6.85[c]
10% KCl	6.81[c,d]
15% iodized NaCl	6.63[d,e]
15% KCl	6.52[e,f]
10% uniodized NaCl	6.39[f,g]
15% uniodized NaCl	6.27[g]

[1] Means with the same letter are not significantly different.

[2] Means calculated from 5 replications.

TABLE 7. Treatment Means for Effect of Salt Type on Emulsification Capacity

Treatment	Mean[1] (ml oil/g yolk)
Iodized NaCl	6.92^{a}
KCl	6.85^{a}
Uniodized NaCl	6.53^{b}

[1] Means with the same letter are not significantly different.

TABLE 8. Treatment Means for Effect of Salt Level on Emulsification Capacity

Treatment	Mean[1] (ml oil/g yolk)
5%	7.14^{a}
10%	6.68^{b}
15%	6.48^{c}

[1] Means with the same letter are not significantly different.

TABLE 9. Treatment Means for Apparent Mayonnaise Viscosity

Treatment	Mean[1,2] (c.p.s.)
10% iodized NaCl	49,250.0[a]
15% iodized NaCl	34,750.0[b]
5% iodized NaCl	29,000.0[c]
15% uniodized NaCl	27,250.0[c,d]
10% uniodized NaCl	26,000.0[d,e]
15% KCl	24,750.0[e]
10% KCl	20,750.0[f]
5% uniodized NaCl	20,000.0[f]
5% KCl	17,250.0[g]
0% salt	10,000.0[h]

[1] Means with the same letter are not significantly different.

[2] Means calculated from 4 readings.

TABLE 10. Treatment Means for Mayonnaise Spread

Treatment	Mean[1,2] (spread units)
0% salt	10.0[a]
5% KCl	7.3[b]
5% uniodized NaCl	6.8[c]
15% KCl	5.4[d]
5% iodized NaCl	5.3[d]
10% uniodized NaCl	5.3[d]
15% uniodized NaCl	5.0[d,e]
15% iodized NaCl	4.9[d,e]
10% KCl	4.5[e,f]
10% iodized NaCl	4.0[f]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 4 readings.

TABLE 11. Treatment Means for Effect of Salt Type on Apparent Mayonnaise Viscosity

Treatment	Mean[1] (c.p.s.)
Iodized NaCl	37,667.0[a]
Uniodized NaCl	24,417.0[b]
KCl	20,917.0[c]

[1]Means with the same letter are not significantly different.

TABLE 12. Treatment Means for Effect of Salt Type on Mayonnaise Spread

Treatment	Mean[1] (spread units)
KCl	5.7[a]
Uniodized NaCl	5.7[a]
Iodized NaCl	4.7[b]

[1]Means with the same letter are not significantly different.

TABLE 13. Treatment Means for Effect of Salt Level on Apparent Mayonnaise Viscosity

Treatment	Mean[1] (c.p.s.)
10%	32,000.0[a]
15%	28,917.0[b]
5%	22,083.0[c]

[1]Means with the same letter are not significantly different.

TABLE 14. Treatment Means for Effect of Salt Level on Mayonnaise Spread

Treatment	Mean[1] (spread units)
5%	6.4[a]
15%	5.1[b]
10%	4.6[c]

[1]Means with the same letter are not significantly different.

TABLE 15. Treatment Means for Mayonnaise Stability

Treatment	Mean[1,2] (days at 40°C)
15% uniodized NaCl	15.0[a]
15% KCl	13.0[b]
15% iodized NaCl	12.3[b]
10% iodized NaCl	8.3[c]
10% uniodized NaCl	8.3[c]
10% KCl	7.0[d]
5% iodized NaCl	5.0[e]
5% uniodized NaCl	4.3[e]
5% KCl	4.3[e]
0% salt	3.0[f]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 3 replications.

TABLE 16. Treatment Means for Effect of Salt Type on Mayonnaise Stability

Treatment	Mean (days at 40°C)
Uniodized NaCl	9.2
Iodized NaCl	8.6
KCl	8.1

TABLE 17. Treatment Means for Effect of Salt Level on Mayonnaise Stability

Treatment	Mean (days at 40°C)
15%	13.4
10%	7.9
5%	4.6

TABLE 18. Treatment Means for Apparent Egg Yolk Viscosity

Treatment	Mean[1,2] (c.p.s.)
90 days frozen storage	14,800.0[a]
30 days frozen storage	2,080.0[b]
60 days frozen storage	2,000.0[b]
0 days frozen storage	684.0[c]
Liquid yolk (10% iodized NaCl)	288.0

[1] Means with the same letter are not significantly different.

[2] Means calculated from 5 replications.

TABLE 19. Treatment Means for Emulsification Capacity

Treatment	Mean[1,2] (ml oil/g yolk)
Liquid yolk (10% iodized NaCl)	6.85
0 days frozen storage	6.39[a]
60 days frozen storage	6.10[b]
90 days frozen storage	6.06[b,c]
30 days frozen storage	5.92[c]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 5 replications.

TABLE 20. Treatment Means for Apparent Mayonnaise Viscosity

Treatment	Mean[1,2] (c.p.s.)
60 days frozen storage	50,250.0[a]
Liquid yolk (10% iodized NaCl)	49,250.0
90 days frozen storage	36,000.0[b]
0 days frozen storage	33,750.0[b]
30 days frozen storage	31,250.0[b]

[1] Means with the same letter are not significantly different.

[2] Means calculated from 4 readings.

TABLE 21. Treatment Means for Mayonnaise Spread

Treatment	Mean[1,2] (spread units)
30 days frozen storage	4.3[a]
0 days frozen storage	4.3[a]
Liquid yolk (10% iodized NaCl)	4.0
90 days frozen storage	3.9[a]
60 days frozen storage	3.0[b]

[1] Means with the same letter are not significantly different.

[2] Means calculated from 4 readings.

TABLE 22. Treatment Means for Mayonnaise Stability

Treatment	Mean (days at 40°C)
0 days frozen storage	22
30 days frozen storage	21
90 days frozen storage	21
60 days frozen storage	20
Liquid yolk (10% iodized NaCl)	8.3

TABLE 23. Treatment Means for Apparent Egg Yolk Viscosity

Treatment	Mean[1,2] (c.p.s.)
Free flow yolk solids	627,200.0[a]
Plain yolk solids	501,200.0[b]
Low viscosity yolk solids	172,400.0[c]
Liquid yolk (10% iodized NaCl)	288.0

[1] Means with the same letter are not significantly different.

[2] Means calculated from 5 replications.

TABLE 24. Treatment Means for Emulsification Capacity

Treatment	Mean[1,2] (ml oil/g yolk)
Liquid yolk (10% iodized NaCl)	6.85
Plain yolk solids	6.33[a]
Free flow yolk solids	6.32[a]
Low viscosity yolk solids	6.02[b]

[1] Means with the same letter are not significantly different.

[2] Means calculated from 5 replications.

TABLE 25. Treatment Means for Apparent Mayonnaise Viscosity

Treatment	Mean[1,2] (c.p.s.)
Liquid yolk (10% iodized NaCl)	49,250.0
Low viscosity yolk solids	38,250.0[a]
Plain yolk solids	28,500.0[b]
Free flow yolk solids	23,000.0[c]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 4 readings.

TABLE 26. Treatment Means for Mayonnaise Spread

Treatment	Mean[1,2] (spread units)
Liquid yolk (10% iodized NaCl)	4.0
Low viscosity yolk solids	3.9[a]
Plain yolk solids	3.3[a]
Free flow yolk solids	3.3[a]

[1]Means with the same letter are not significantly different.

[2]Means calculated from 4 readings.

TABLE 27. Treatment Means for Mayonnaise Stability

Treatment	Mean (days at 40°C)
Frozen yolk (average)	21
Free flow yolk solids	12
Plain yolk solids	10
Low viscosity yolk solids	10
Liquid yolk (10% iodized NaCl)	8.3

TABLE 28. Mayonnaise Microbiology

Treatment	Standard Plate Counts[1] Before	Standard Plate Counts[1] After	Mold and Yeast Counts[1] Before	Mold and Yeast Counts[1] After
Liquid yolk				
0% salt	1.7×10^4	1.1×10^3	0.00	0.25
5% iodized NaCl	2.9×10^3	1.5×10^3	0.25	0.00
10% iodized NaCl	2.8×10^3	2.5×10^3	0.00	0.25
15% iodized NaCl	6.3×10^1	2.7×10^3	0.00	0.00
5% uniodized NaCl	2.1×10^3	1.9×10^2	0.00	0.25
10% uniodized NaCl	3.2×10^3	2.5×10^3	0.00	0.50
15% uniodized NaCl	3.9×10^3	2.5×10^3	0.25	0.00
5% KCl	$>1.7 \times 10^4$	1.6×10^3	0.00	0.25
10% KCl	$>1.7 \times 10^4$	2.3×10^3	0.00	0.25
15% KCl	$>1.7 \times 10^4$	2.2×10^3	0.00	0.00
Frozen yolk				
0 days	1.9×10^3	2.0×10^3	0.00	0.25
30 days	2.6×10^3	1.3×10^3	0.25	0.00
60 days	2.8×10^3	3.0×10^2	0.00	0.00
90 days	2.0×10^3	2.8×10^3	0.00	0.00
Yolk solids				
Plain	3.2×10^2	2.6×10^3	0.00	0.25
Free flow	2.1×10^2	2.4×10^3	0.00	0.00
Low viscosity	1.6×10^3	1.7×10^3	0.00	0.00

[1] Means calculated from 4 readings.

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PROPERTIES OF SEVERAL TYPES OF SALTED YOLK AND FUNCTIONALITY IN MAYONNAISE

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ABSTRACT

Viscosity, emulsification capacity, and functionality in mayonnaise of several types of salted yolk were studied.

The effects of salt type and level on the yolk properties were determined in the liquid yolk study. The addition of iodized NaCl, uniodized NaCl, or KCl resulted in an increase in yolk viscosity and a decrease in emulsification capacity. Viscosity of yolk increased as salt level increased from 5 to 15%, while emulsification capacity decreased as salt level increased. Mayonnaise made from liquid yolk containing any of the 3 salts had a higher apparent viscosity, lower spread, and higher stability than that made from liquid yolk with 0% salt.

Frozen storage of yolk containing 10% iodized NaCl for 0, 30, 60, and 90 days resulted in increased apparent yolk viscosity and decreased emulsification capacity. Mayonnaise made from yolk stored 60 days had a higher apparent viscosity and a lower spread than that made from any other frozen yolk sample. Mayonnaise made from all frozen yolk samples had stability values of greater than or equal to 20 days.

Plain, free flow, and low viscosity yolk solids had higher apparent viscosities, and lower emulsification capacities than liquid yolk. All 3 types of yolk solids produced mayonnaise with lower viscosities and lower spreads than that made from liquid yolk. Stability values for mayonnaise made from the 3 types of yolk solids were intermediate between those for mayonnaise made from liquid yolk (lowest overall stability) and that made from frozen yolk (highest overall stability).